Wind-induced day-ahead and hour-ahead imbalances in a power system with a significant wind mix: Simulations in the Danish experience

Litong-Palima, Marisciel; Cutululis, Nicolaos Antonio; Detlefsen, Nina; Sørensen, Poul Ejnar

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Litong-Palima, M., Cutululis, N. A., Detlefsen, N., & Sørensen, P. E. (2012). *Wind-induced day-ahead and hour-ahead imbalances in a power system with a significant wind mix: Simulations in the Danish experience*. Poster session presented at EWEC 2012 - European Wind Energy Conference & Exhibition, Copenhagen, Denmark.

Wind-induced Day-Ahead and Hour-Ahead Imbalances in a Power System with a Significant Wind Mix: Simulations in the Danish Experience

PO. ID 171

Marisciel Litong-Palima[1], Nicolaos Cutululis[1], Nina Detlefsen[2] and Poul Sørensen[1]
[1] DTU Wind Energy, Risø Campus, Roskilde, Denmark [2] Energinet, Fredericia, Denmark

Correspondence: Marisciel Litong-Palima, Email: mlit@dtu.dk

DTU Wind Energy
Department of Wind Energy
ENERGINET.DK

Abstract

We describe the **wind forecast module** that is a component of the **Simulation of Balance (SimBa)**[1] software being developed by the Danish transmission system operator (TSO), Energinet.dk. **SimBa** is simulation software that Energinet is developing to assist in the day-ahead and hour-ahead balancing and scheduling of the entire power market system in Denmark.

As part of the SimBa effort, we present results here to simulate the imbalances that wind resources bring into the Danish power system. The core of the wind forecast module is the characterization of the imbalances as an ARMA(1,1) [2] process. Once the imbalances are characterized, it provides a way to estimate the objective series related to wind power production, namely:

- OUTPUT 1: The day-ahead available power measurements $\mathbf{P_{DA}}$ and;
- OUTPUT 2: The hour-ahead power forecasts $\mathbf{F_{HA}}$.

We interpret the wind-induced imbalances as the error **E** or simply the difference between the forecasts **F** and the measured available power **P**. The forecasts are from Energinet's in-house forecasting system while the power measurements are based on Energinet's actual accounting records of power that were produced, delivered and paid. The data covers the winter times from the late 2009 until 2011 for the entire Danish system. We then fit an ARMA(1,1) to each daily error series and determine the set of parameters that give the lowest mean absolute error (MAE) for the entire data set. Using the least-MAE parameter set, we simulate an error series with the horizon tuned to the day-ahead and use this to adjust the day-ahead forecasts, $\mathbf{F_{DA}}$, which is the input to the forecast module. This gives the first series output of SimBa. Using another ARMA(1,1) error series, with the horizon tuned to the hour-ahead, we adjust the previously calculated available power series $\mathbf{P_{DA}}$ and obtain the hour-ahead forecasts $\mathbf{F_{HA}}$ for each hour of the day of operation. We show the results here for the aggregated onshore wind farms.

The SimBa Motivation

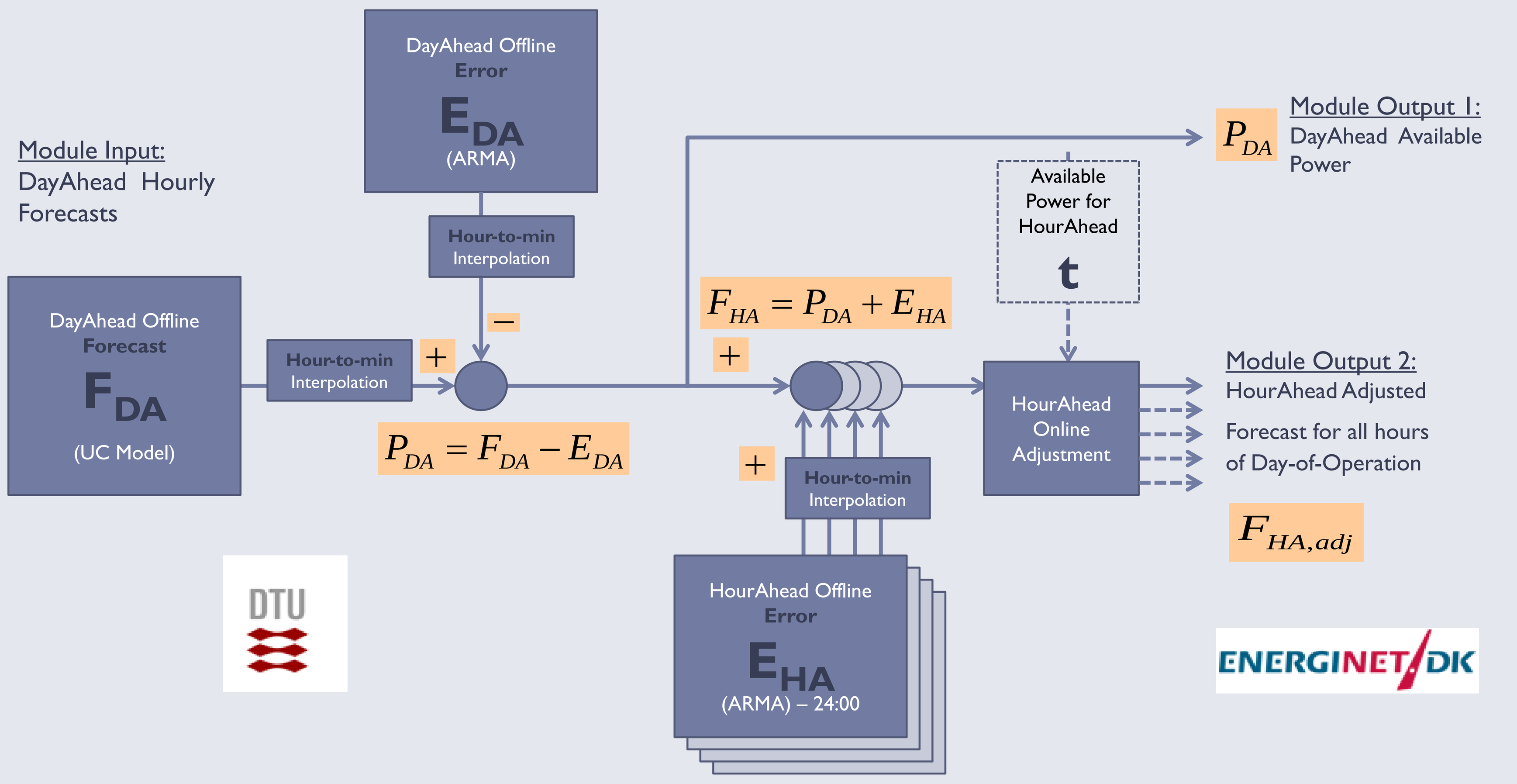
% Wind Portion in Total Production (DK)	
2010	22[3]
2020	50[4]

In 2011, the Danish government has committed to a fossil-fuel-free Denmark by the year 2050.[5]

As Denmark spearheads the global effort in developing wind energy as a veritable option to fossil fuels, it also finds itself at the forefront of confronting the accompanying challenges of integrating wind power into the grid. The Danish power system is characterized by a high wind contribution that is estimated at 22% in 2010 and is targeted to hit 50% in the year 2020.

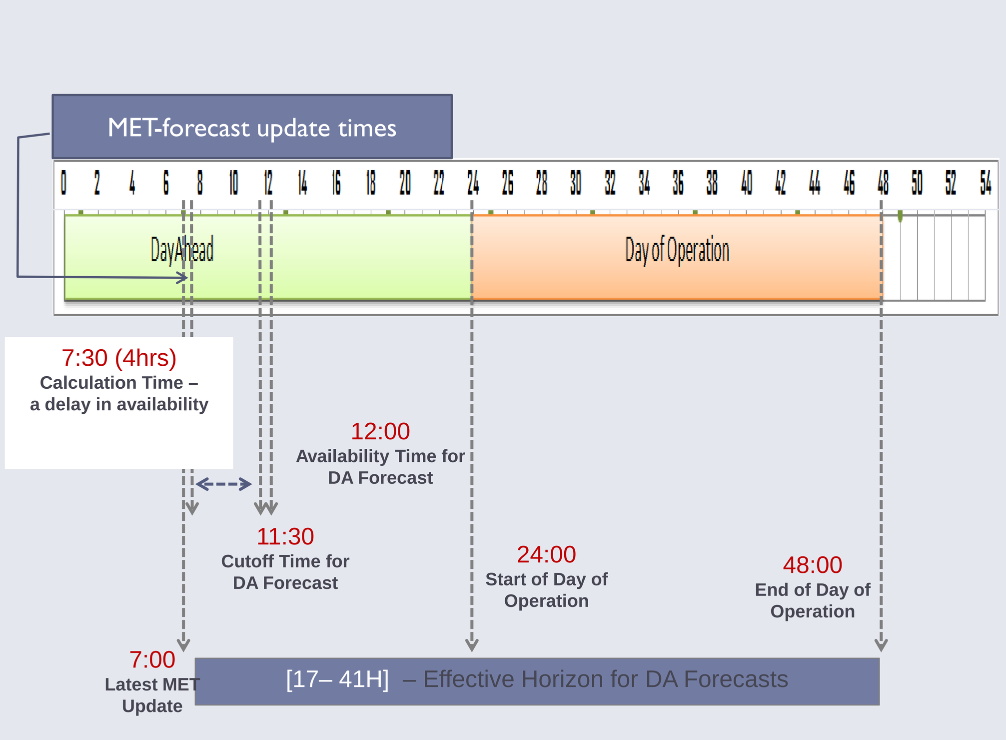
To address this high wind penetration challenge in part, the Danish transmission system operator (TSO) Energinet, is developing **SimBa** to aid in quantifying the imbalance that wind production can introduce into the Danish power system. There are already available a number of approaches and methods that suggest how to incorporate wind production forecasts at the system level. Among these approaches, SimBa is unique in the sense that it is geared towards real time balancing. SimBa is pioneering the effort to simulate the balancing of the production and consumption at the intra-hour scale, and it does this for a system with a characteristically significant wind portion.

Overview of the SimBa Forecast Module



The input to the forecast module is the hourly day-ahead wind power forecasts, $\mathbf{F_{DA}}$, from the unit commitment (UC) model. The forecast module of SimBa is configured to calculate the day-ahead (DA) available power, $\mathbf{P_{DA}}$, and the hour-ahead (HA) forecasted power, $\mathbf{F_{HA}}$, for the power output from wind farms in the Denmark, aggregated into two main areas: the DK1 (western) and DK2 (eastern).

DA Forecast Horizon – Winter Time

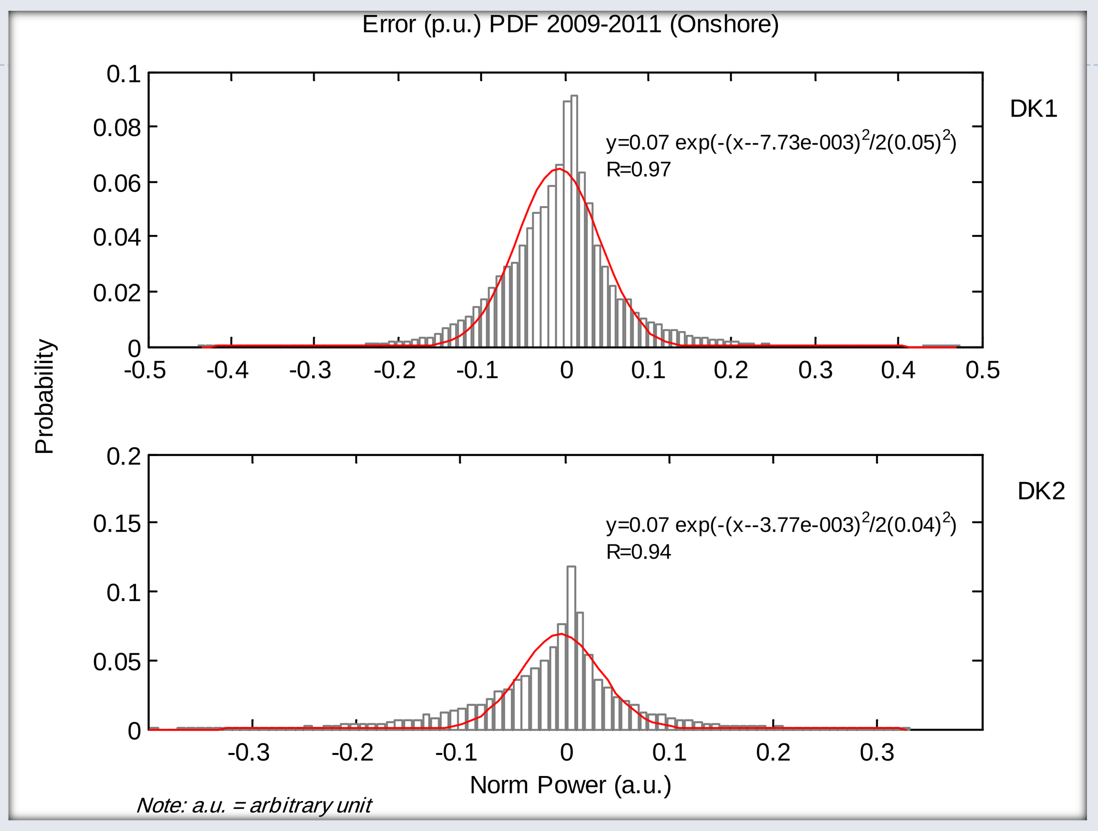


Tuning of the ARMA process to the Day-Ahead horizon

- **Power forecasts are based on the meteorological (MET) speed forecasts released on the hours UTC {0,6,12,18}.**
- **In Denmark (UTC+1), the corresponding hours are CET {1,7,13,19} .**
- **Cutoff time for the release of the day-ahead forecasts is at 11:30 AM (market schedule).**
- **Calculation time introduces a delay of about 4 hours in the update of power forecasts . Hence, the calculation of the day-ahead forecasts at cutoff time 11:30AM are initiated as early as, for example 7:30 AM.**
- **At 7:30AM during winter times, the most recently available MET forecast is released at 7AM. From 7AM until the day of operation, the horizon is effectively in the range of 17-41 hours.**
- **The day-ahead horizon can vary for the summer time, because themarket schedule follows the summer time. Hence, the MET forecasts are releases at hours CEST{2,8,14,20}**
- **A similar horizon tuning step is done for the hour-ahead calculations.**

Results

Error as an ARMA(1,1) Process



What is ARMA(1,1) ?

ARMA stands for the autoregressive (**AR**) and moving-average (**MA**), with each component defined with one parameter. It is a standard technique in forecasting in general, and quite recently in the forecasting of wind speed and power.[6]

The defining Equations of ARMA(1,1)

$$\varepsilon(k) = \alpha\,\varepsilon(k-1) + Z(k) + \beta\,Z(k-1)$$
$$\varepsilon(0) = 0$$
$$Z(0) = 0$$

Where ;
$\varepsilon(k)=$ error value at the k-th time index,
$Z(k)=$ random Gaussian variable with std σ_Z,
$\alpha,\beta=$ the AR and MA parameters.

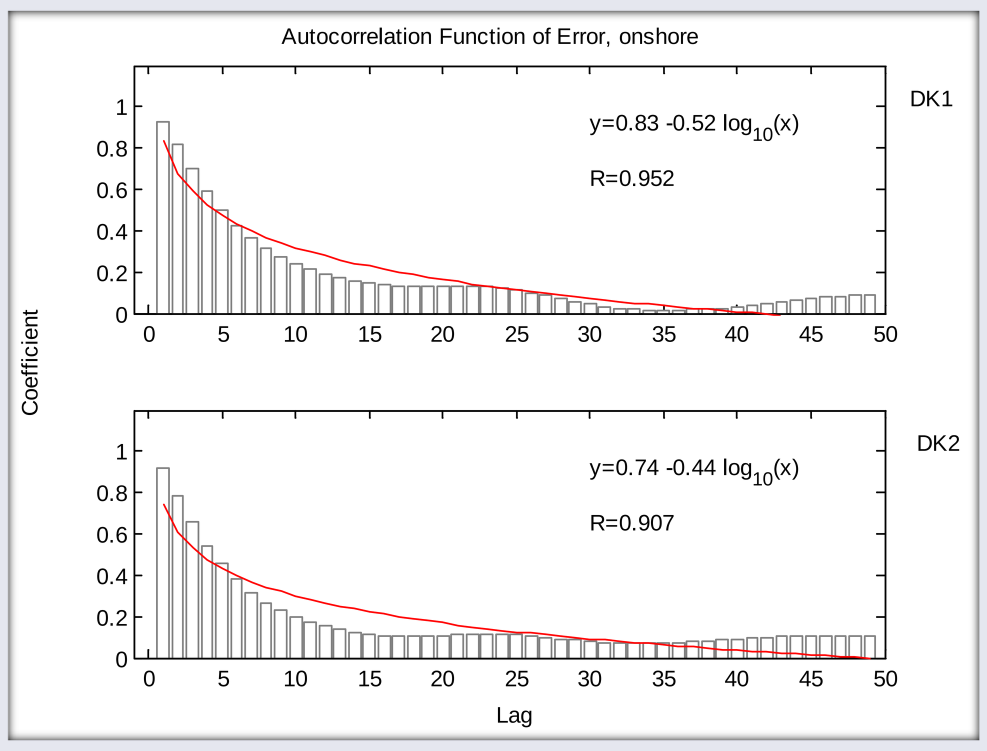
Error as an ARMA(1,1) Process

In this work, we focus not on the power forecast itself, but on its "error" and identify it as an independent ARMA process.[7] This is at the core of the SimBa wind forecast module.

Characteristics of the Error Process

As a random process, the error process satisfies the ARMA conditions as;

- The probability distribution is well-fitted by a Gaussian pdf.
- The auto-correlation function has a logarithmic decay, which is slower than an exponential decay.



Mean Absolute Error (MAE) for the DA and HA

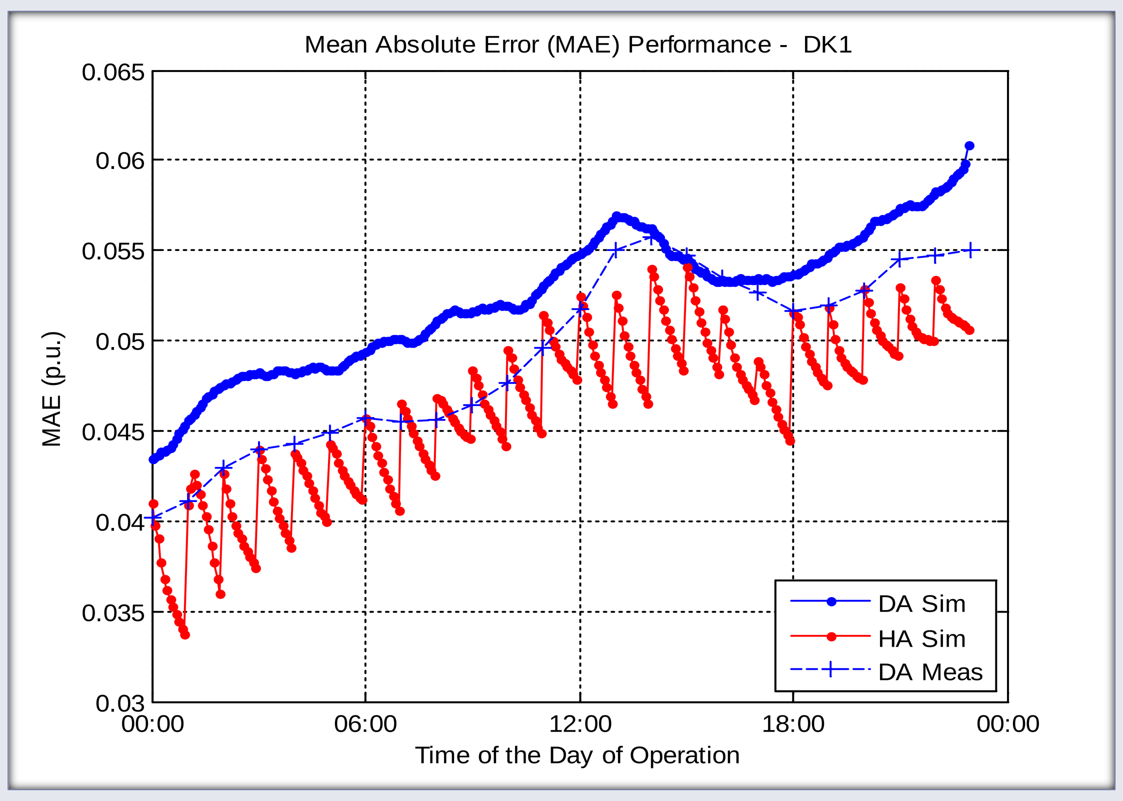
MAE Performance of the Forecast Module

. Using the ARMA parameter set that gives the least MAE for the given historical data, we simulate the performance of the forecast module for the $\boldsymbol{P_{DA}}$ and $\boldsymbol{F_{HA}}$ output series.

- Based on the MAE, the simulated errors mirror the trend in the actual, measured errors, at a slightly higher MAE level (increase of < 0.5%).
- As expected, the hour-ahead forecasts allows for a better performance than the day-ahead results.

Hour-Ahead Online Adjustment

The sawtooth-like feature of the $\boldsymbol{F_{HA}}$ output series is due to the online adjustment that Energinet implements on its online forecasts. Every hour, a given forecast is adjusted to begin at the most recently obtained power measurement and to slowly merge with the rest of the forecast.



Conclusions

To implement the forecast module of SimBa, we propose a procedure that is based mainly on a single ARMA model of the error between the forecasts and the measurements of the wind power production in Denmark (late 2009-2011, winter times).

Using a single error model tuned to the relevant horizon, we calculate the two output series of the module in sequence. In particular, we use the day-ahead version $\boldsymbol{E_{DA}}$ of the error model to estimate the available wind power $\boldsymbol{P_{DA}}$ from the given day-ahead power forecasts $\boldsymbol{F_{DA}}$. Next, we use the hour-ahead version $\boldsymbol{E_{HA}}$ of the same error model to estimate the hour-ahead forecast series $\boldsymbol{F_{HA}}$ from the previously estimated available wind power $\boldsymbol{P_{DA}}$.

We justify the use of the ARMA(1,1) process to model the error series by showing that its probability distribution is fitted by a Gaussian function and that its autocorrelation function has a slow logarithmic decay to zero. We assume that the same process is relevant to both the day-ahead and hour-ahead calculations via a suitable tuning of the error horizon.

Based on the MAE performance for the day-ahead adjustments, the day-ahead ARMA error simulations mirror the measured errors well, albeit at a slightly higher MAE level (< 0.5%). The hour-ahead performance shows an improvement over the day-ahead results.

References

1. A. B. Hansen, A. Orths, K. Falk, N. K. Detlefsen. (October, 2011). *Danish Fossil Independent Energy System 2050 - From Strategic Investigations to Intra-Hour Simulation of Balancing Issues*. Unpublished paper presented at **The 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants**, Aarhus, DK.
2. NIST/SEMATECH e-Handbook of Statistical Methods, Retrieved April 4, 2012, from http://www.itl.nist.gov/div898/handbook/.
3. International Energy Agency (IEA) Wind Energy Annual Report (Year 2010), Published 2011.
4. The Danish Government. Our Future Energy 2011. Retrieved April 4, 2012, from http://www.ens.dk/Documents/Netboghandel%20-%20publikationer/2011/our_future_energy_%20web.pdf.
5. The Danish Government. Energy Strategy 2050. Published February 2011. Retrieved April 4, 2012, from http://www.denmark.dk/NR/rdonlyres/2BD031EC-AD41-4564-B146-5549B273CC02/0/EnergyStrategy2050web.pdf.
6. A. Costa, A. Crespo, J. Navarro, G. Lizcano, H. Madsen, and E. Feitosa, "A review on the young history of the wind power short-term prediction," Renewable and Sustainable Energy, vol. 12, pp. 1725–1744, 2008.
7. Pinson, P. and Kariniotakis, G. (2004), On-line assessment of prediction risk for wind power production forecasts. Wind Energ., 7: 119–132. doi: 10.1002/we.114

EWEA 2012, Copenhagen, Denmark: Europe's Premier Wind Energy Event